

## **TITLE OF THE INVENTION**

INVERTER DEVICE AND METHOD OF MANUFACTURING THE DEVICE  
THEREOF, AND ELECTRIC AUTOMOBILE INCORPORATING THE INVERTER  
DEVICE THEREOF

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## **CROSS-REFERENCE TO RELATED APPLICATION**

This application claims benefit of priority to Japanese  
Application No. JP 2003-321462 filed 12th September, 2003,  
the entire content of which is incorporated by reference  
10 herein.

## **BACKGROUND OF THE INVENTION**

### **1. Field of the Invention**

The present invention relates to an inverter device of  
15 high reliability which is of small size and excellent  
cooling efficiency, and a method of manufacturing the  
inverter device thereof and an electric automobile  
(sometimes called an electric vehicle or an electric car)  
incorporating the inverter device thereof.

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### **2. Description of the Related Art**

Miniaturization and improvement of reliability of power  
semiconductor elements and inverter devices employing these  
are being demanded. When semiconductor elements and inverter  
25 devices employing these are employed in an electric

automobile, reduction in size and improved reliability are particularly important.

In order to achieve reduced size and improved reliability of power semiconductor elements and inverter devices employing these, power semiconductor elements and inverter devices are required that have excellent cooling efficiency such as Japanese Laid-Open patent 2003-153554.

The construction of a conventional inverter device is described below with reference to Figure 1 and Figure 2.

Figure 1 is a partial axial cross-sectional view showing the mounting structure of semiconductor chips in the interior of a power semiconductor element; Figure 2 is a partial perspective view of a power semiconductor element.

In the inverter device shown in Figure 2, a single arm of a three-phase inverter is constituted by connecting in parallel a plurality of IGBTs (insulated gate bipolar transistors) 171 and diodes 181 constituted by semiconductor chips of size no more than 10 mm square; furthermore, a plurality of semiconductor chips constituting a single arm of the three-phase inverter are bonded with a conductor 20 of thickness between 1.5 mm and 5 mm; the conductor 20 is adhesively fixed to a cooler 22 by a ceramics-containing insulating resin sheet 23. ("10 mm square" or " $\square$ 10 mm" indicates that the length of one side of a square shape is 10 mm.)

Furthermore, in the inverter device shown in Figure 2, four parallel-connected IGBTs 171A to 171D constituting an upper arm of the W phase of a three-phase inverter and two parallel-connected diodes 181A to 181B are arranged in a single row with an upper arm conductor 25 constituting an upper arm of the three-phase inverter; likewise, four parallel-connected IGBTs 172A to 172D constituting a lower arm of the W phase of a three-phase inverter and two parallel-connected diodes 182A to 182B are arranged in a single row with a lower arm conductor 26 constituting a lower arm of a three-phase inverter. In addition, a three-phase output conductor 27 that connects three-phase output terminal 32 with the IGBTs 171A to 171D and the diodes 181A to 181B is arranged on the upper arm conductor 25 between the upper arm conductor 25 and the lower arm conductor 26.

The construction of the upper arms and the lower arms will now be described. The arms are as follows in the case of an inverter device that converts DC current to three-phase AC current as shown in Figure 3. Specifically, in order to generate three-phase AC power from DC battery power, an inverter is constituted comprising three-phase arms (U phase, X phase), (V phase, Y phase) and (W phase, Z phase) and conversion to AC current is effected therein. This AC current provides three-phase AC power for driving a three-phase motor.

The upper arms are constituted by the U phase, V phase and W phase and the lower arms are constituted by the X phase, Y phase and Z phase.

In Figure 2, the lower arm conductor 26 and the three-  
5 phase output conductor 27 are constituted by the same conductor. In addition, a negative electrode conductor 28 that connects the negative electrode terminal 31 with the IGBTs 172A to 172D and the diodes 182A to 182B arranged on the lower arm conductor 26 is arranged between the upper arm  
10 conductor 25 and the lower arm conductor 26. Electrical connection is effected by means of wire bonding 29 between the respective conductors and the IGBTs and diodes.

In the inverter device shown in Figure 1 to Figure 2 the IGBTs 171A to 171D and the diodes 181A to 181C bonded with  
15 the conductor 20 and/or upper arm conductor 25 and lower arm conductor 26 are directly connected with a cooler 22 using insulating resin sheet 23, so the thermal resistance of the IGBTs and diode chips within the interior of the power semiconductor element is reduced. Furthermore, since the  
20 IGBTs 171A to 171D and diodes 181A to 181C are bonded with the conductor 20 and/or upper arm conductor 25 and lower arm conductor 26 of thickness between 1.5 mm and 5 mm, the thermal time constant becomes large, due to the effect of the thermal capacity of the conductor 20 and/or upper arm  
25 conductor 25 and lower arm conductor 26, with the result that transient thermal resistance become small and the rise

in temperature during start-up of the inverter becomes small. Cooling efficiency is therefore improved and miniaturization of the inverter device can be achieved.

However, with the conventional inverter device, although  
5 the thermal resistance of the IGBTs and the diode chips in the interior of the power semiconductor elements was reduced, there were the following problems.

First of all, manufacturing time was prolonged since considerable time was required to provide the plurality of  
10 wire bonding locations involved in the electrical wiring of the plurality of parallel-connected IGBTs or diode chips by wire bonding.

Also, there were structural limits to the extent to which the cooling efficiency could be improved.

15 Accordingly, one object of the present invention is to provide a novel inverter device and method of manufacturing the device thereof and an electric automobile incorporating this inverter device wherein power semiconductor elements, that provide excellent manufacturing characteristics, are  
20 employed, in order to improve current capacity and reduce the size of the inverter device, but wherein the cooling efficiency of the power semiconductor elements is further improved.

## 25 SUMMARY OF THE INVENTION

In order to achieve the above object, an inverter device according to the present invention is constructed as follows. Specifically, an inverter device according to the present invention comprises: a plurality of parallel-connected  
5 semiconductor chips constituting an arm of an inverter;  
a first conductor to which one face of this plurality of semiconductor chips is connected;  
a wide conductor to which the other face of this plurality of semiconductor chips is connected;  
10 a second conductor connected to the wide conductor; and  
a cooler to which said first conductor and second conductor are adhesively fixed, with an insulating resin sheet interposed therebetween.

According to the present invention, the current capacity  
15 of the inverter device can be improved and reduction in size and improved reliability also achieved.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

A more complete appreciation of the present invention  
20 and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

Figure 1 is a partial vertical cross-sectional view  
25 showing the mounting structure of semiconductor chips within the interior of a conventional power semiconductor element;

Figure 2 is a partial perspective view of a conventional power semiconductor element;

Figure 3 is a view given in explanation of the construction of an arm;

5        Figure 4 is a partial perspective view showing the mounting structure of an inverter device according to a first embodiment of the present invention;

Figure 5 is a view showing the results of analysis of heat flux showing the heat discharge paths of loss of heat  
10       generated by a semiconductor chip during passage of current by the inverter device of Figure 4;

Figure 6 is a view showing the results of analysis of transient thermal resistance of a semiconductor chip of the inverter device of Figure 4;

15       Figure 7 is a partial perspective view showing the mounting structure of an inverter device according to a second embodiment of the present invention;

Figure 8A, Figure 8B and Figure 8C are respectively partial perspective views showing the sequence of  
20       manufacturing an inverter device according to the second embodiment of the present invention;

Figure 9 is a simplified transparent perspective view of the case where an inverter device according to the present invention is incorporated in an electric automobile; and

25       Figure 10 is a simplified transparent perspective view of the case where an inverter device according to the

present invention is incorporated in an electric automobile that also incorporates an internal combustion engine.

#### **DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

5 Referring now to the drawings, wherein like reference numerals designate identical or corresponding parts throughout the several views, and more particularly to Figure 4 thereof, one embodiment of the present invention will be described.

10 Figure 4 is a partial perspective view showing the mounting structure of an inverter device according to a first embodiment of the present invention. Figure 5 is a view showing the results of analysis of heat flux showing the heat discharge paths of loss of heat generated by a  
15 semiconductor chip during passage of current by the inverter device of Figure 4. Figure 6 is a view showing the results of analysis of transient thermal resistance of a semiconductor chip of the inverter device of Figure 4.

In the inverter device of Figure 4, one arm of the  
20 three-phase inverter is constituted by connecting in parallel IGBTs 171A to D and diodes 181A to B and IGBTs 172A to D and diodes 182A to B, which are semiconductor chips of size less than 10 mm square ("10 mm square" indicates that the length of one side of a square shape is 10 mm.). Figure  
25 4 shows the case where four IGBTs are connected in parallel and two diodes are connected in parallel.



Furthermore, four parallel-connected IGBTs 171A to 171D constituting an upper arm of a three-phase inverter and two parallel-connected diodes 181A to 181B are arranged in a single row with an upper arm conductor 25 constituting an upper arm of a three-phase inverter; likewise, four parallel-connected IGBTs 172A to 172D constituting a lower arm of the three-phase inverter and two parallel-connected diodes 182A to 182B are arranged in a single row with a lower arm conductor 26 constituting a lower arm of the three-phase inverter.

In addition, three-phase output conductors 27 that connect three-phase output terminals 32 with the IGBTs 171A to 171D and the diodes 181A to 181B are arranged on the upper arm conductor 25 between the upper arm conductor 25 and the lower arm conductor 26. In the embodiment of Figure 4, the lower arm conductor 26 and the three-phase output conductor 27 are constituted by the same conductor.

In addition, a negative electrode conductor 28 that connects the negative electrode terminal 31 with the IGBTs 172A to 172D and the diodes 182A to 182B arranged on the lower arm conductor 26 is arranged between the upper arm conductor 25 and the lower arm conductor 26.

The thickness of the upper arm conductor 25 and lower arm conductor 26 and three-phase output conductor 27 and negative electrode conductor 28 is about 1.5 mm to 5 mm. The IGBTs and the diodes are arranged dispersed by distances of

at least twice the thickness of the aforesaid conductors and are bonded with the conductors by low melting point solder such as Sn/Pb or high melting point solder such as Sn/Ag/Cu. The inventors of the present invention believe that the  
5 latter i.e. high melting point solder will often be used in future in view of environmental engineering aspects.

In addition, the upper arm conductor 25 and lower arm conductor 26 and three-phase output conductor 27 and negative electrode conductor 28 are adhesively fixed to the  
10 cooler 22 by means of a ceramics-containing insulating resin sheet 23. The insulating resin sheet 23 is filled with ceramic filler such as for example boron nitride in the insulating resin and has a thermal conductivity of 2 to 4 W/mK and a thickness of about 0.05 to 0.15 mm.

15 In addition, a wide conductor 33 is bonded with the upper parts of the IGBTs and diodes by means of low melting point solder such as Sn/Pb or high melting point solder such as Sn/Ag/Cu, so that these are electrically connected by means of the three-phase output conductor 27 and negative  
20 electrode conductor 28 and wide conductor 33.

The upper arm conductor 25 and positive electrode terminal 30, and the three-phase output conductor 27 and three-phase output terminal 32, and the negative electrode conductor 28 and negative electrode terminal 31 are  
25 electrically connected by means of an input/output conductor 34.

Since the material of the IGBTs 171 and IGBTs 172 and of the diodes 181 and diodes 182 is silicon (Si), while the material of the various conductors is copper (Cu), the linear expansion coefficient of the IGBTs and diodes and the conductors differ. As a result, when loaded by the temperature cycle, shearing stress is generated in the solder bonding the IGBTs and diodes with the conductors, resulting in the production of non-linear strain. If the value of the non-linear strain becomes large, cracking etc is generated in the solder when loaded by the temperature cycle. Reduction of the value of the non-linear strain improves reliability and durability.

Consequently, when the chip size of the IGBTs and diodes is large, non-linear strain of the solder is increased. It is therefore necessary to keep the chip size below about 10 mm square in order to ensure reliability and durability of the inverter device.

However, if the chip size is less than 10 mm square, the current capacity per chip is small, so in order to construct an inverter device of a few tens of kW for use in an electric automobile, chips must be connected in parallel.

Also, in order to reduce the rise in temperature in particular on start-up of the inverter and in order to reduce the steady thermal resistance by the heat dispersion effect of the conductors, the thickness of the upper arm conductor 25 and lower arm conductor 26 and three-phase

output conductor 27 and negative electrode conductor 28 is preferably 1.5 to 5 mm.

A three-phase RST AC power source is only produced by providing three such inverters (elements) having three-phase  
5 output terminals 32.

Figure 5 shows the results of analysis of heat flux in a steady condition, showing the flow of heat loss when cooling is effected by thermal conduction of heat loss generated in an IGBT 172A constituted by a semiconductor chip to the  
10 cooler 22 during passage of current by the inverter device. The arrows show the direction of the heat flux and the magnitude of the arrows shows the magnitude of the heat flux.

Figure 6 shows the results of analysis comparing the transient thermal resistance of the prior art power  
15 semiconductor element shown in Figure 1 and Figure 2 and a semiconductor chip of a power semiconductor element according to the present invention.

In the prior art power semiconductor element, the wire bonding is extremely fine, so the thermal resistance is  
20 extremely large. Consequently, as shown in Figure 5, practically all of the heat loss generated in the IGBT 172A is thermally conducted to the lower arm conductor 26 and emitted to the cooler 22.

In contrast, as shown in Figure 5, in the case of a  
25 power semiconductor element according to the present invention, part of the heat loss generated in the IGBT 172A

is thermally conducted to the wide conductor 33 and thence thermally conducted to the negative electrode conductor 28, while another part thereof is thermally conducted to the lower arm conductor 26 and is thence conducted to the cooler 22, thereby achieving cooling.

In this analysis, it is assumed that the thickness of the wide conductor 33 is 3 mm, and the thickness of the lower conductor 26 and negative electrode conductor 28 is 3 mm. In order to promote thermal conduction from the wide conductor 33, since large cross-sectional area implies small thermal resistance, preferably the wide conductor should have some degree of thickness (of the order of a few mm). Although the thermal resistance can be reduced by making the cross-sectional area large, the problem of increased weight is generated.

As described above, according to the present invention, both faces of the IGBT 172A are cooled, by means of the wide conductor 33 and the lower arm conductor 26, so, as shown in Figure 6, the steady thermal resistance after 10 to 20 sec is lowered by about 25% compared with that of a conventional power semiconductor element. The transient thermal resistance for 0.1 to 0.3 sec on start-up of the inverter, which used to present a problem, is also reduced by about 50% compared with that of the prior art power semiconductor element, due to cooling of both sides of the wide conductor 33 and the thermal capacity effect.

Also, if, in a power semiconductor element according to the present invention, the electrical wiring is completed by bonding the IGBTs and diodes and conductors and wide conductor using solder, the steps of wiring a plurality of wire bonding locations, as in the prior art power semiconductor element, become unnecessary, reducing the manufacturing time.

In this way, in an inverter device according to the first embodiment, the thermal resistance of the IGBTs and diode chips in the interior of the power semiconductor element is further reduced, both on inverter start-up and in the steady condition, thereby lowering the rise in temperature of the IGBTs and diode chips and improving cooling efficiency. In this way, improvement in reliability and size reduction of the inverter device can be achieved and the manufacturing yield (manufacture yield) of the power semiconductor element can also be improved.

Next, a second embodiment of the present invention will be described.

Figure 7 is a partial perspective view showing the mounting structure of an inverter device according to a second embodiment of the present invention. Figure 8A, Figure 8B and Figure 8C are partial perspective views showing the manufacturing sequence of an inverter device according to the second embodiment of the present invention.

In Figure 7, heat buffer plates 35 are bonded by low melting point solder such as Sn/Pb or high melting point solder such as Sn/Ag/Cu with the upper parts of the semiconductor chips constituting IGBTs 171A to D and diodes 181A to B and IGBTs 172A to D and diodes 182A to B of the power semiconductor element and the wide conductor 33 is adhesively fixed by electrically conductive adhesive to the top of the heat buffer plates 35.

The material of the heat buffer plates 35 is for example molybdenum (Mo) or the like, which has a linear expansion coefficient close to that of the semiconductor chips and its thickness is about 0.5 mm. The electrically conductive adhesive has a heat conductivity of about 15 to 60 W/mK and is for example an adhesive whose matrix consists of insulating resin but which is filled with a conductive substance such as silver filler. Other details concerning the construction are the same as in the first embodiment.

In the above construction, heat buffer plates 35 and conductive adhesive are interposed between the semiconductor chips and the wide conductor 33, but, if for example the heat buffer plates 35 are made of molybdenum, with a thickness of 0.5 mm and the thermal conductivity of the electrically conductive adhesive is 15 W/mK, albeit the thermal resistance is about 5% greater than that of the first embodiment, the steady resistance after 10 to 20 sec

is reduced by about 20% compared with the prior art power semiconductor element.

Furthermore, as shown in Figure 8B, first of all, the IGBTs 171A to D and diodes 181A to B and IGBTs 172A to D and  
5 diodes 182A to B and heat buffer plates 35 and the aforesaid conductors of the power semiconductor element according to the present invention are bonded by low melting point or high melting point solder.

After this, adhesive fixing by heating of the conductors  
10 and the cooler 22 using insulating resin sheet 23 and, in addition, adhesive fixing by heating of the heat buffer plates 35 and the wide conductor 33 is effected using electrically conductive adhesive, in respective steps at the same temperature.

15 Furthermore, since the wide conductor 33 is divided for each semiconductor chip, adhesive fixing using pressure and heat is effected using insulating resin sheet 23 by applying pressure to the conductors and cooler 22 at the locations where a plurality of semiconductor chips are not bonded on  
20 each conductor.

With a power semiconductor element manufactured as described above, adhesive fixing with the cooler 22 by pressure and heating can be achieved using the insulating resin sheet 23 in steps at the same temperature with the  
25 respective conductors in an independent condition, but in a condition in which the conductors are not integrated with



the wide conductors 33 by solder bonding, as they are in the first embodiment, even when variations occur in the degree of planarity or warping of the adhesive fixing surfaces of the conductors with respect to the cooler, in the case of upper arm conductors 25 and lower arm conductors 26 and the three-phase output conductors 27 and negative electrode conductors 28 wherein the output capacity of the inverter is large, increasing the number of semiconductor chips arranged in parallel and increasing the length of the conductors. Adhesive fixing can therefore be achieved in a condition in which the cooler 22 and the conductors are totally integrated.

Thus, in this second embodiment, even if the output capacity of the inverter device is increased, the manufacturing yield of the power semiconductor elements can be improved and, both during inverter start-up and in the steady condition, the temperature rise of the IGBTs and diode chips is low, being practically equivalent to that of the first embodiment, and the cooling effect is improved.

Figure 9 is a diagrammatic transparent perspective view showing the case in which an inverter device as described above is incorporated in an electric automobile. The inverter device 91 as described above is incorporated in the interior of the front part of the vehicle body 90 of the electric automobile, and a three-phase electric motor 92 that is supplied with power by this inverter device is

provided in the vehicle body 90. Drive wheels 93 are driven by this three-phase electric motor 92, supplying propulsive force to the electric automobile.

Figure 10 is a diagrammatic transparent perspective view showing the case in which an inverter device as described above is incorporated in an electric automobile. The inverter device 101 as described above is incorporated in the interior of the front part of the vehicle body 100 of the electric automobile, and a three-phase electric motor 102 that is supplied with power by this inverter device is provided in the vehicle body 100. Drive wheels 103 are driven by this three-phase electric motor 102, supplying propulsive force to the electric automobile.

This vehicle body 100 also incorporates an internal combustion engine 104 and the drive wheels 103 are also driven by this internal combustion engine 104. Such an electric automobile is termed a so-called hybrid vehicle, in which the drive wheels 103 are driven as required by the three-phase electric motor 102 and/or the internal combustion engine 104.

Although the above description was in respect of an inverter device employed in an electric automobile, the present invention is not restricted to this and could of course be applied to other applications. The present invention can usefully be applied in particular to elevators or electric trains.

Furthermore according to the above description IGBT is used as a semiconductor chip, however, other semiconductor chips such as MOSFET (Metal Oxide Semiconductor Field Effect Transistor) and the like may be used with the same result.

- 5 Not only Si but also SiC with a wide gap semiconductor as material of the semiconductor chip may be used with the same result.